# A New Resource Management Scheme for Ad Hoc and Sensor Networks

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***Abstract*— Ad hoc and sensor networks have received tremendous attention in the recent literature due to its unpredictable nature and its many applications. Imposing any kind of reliability in such networks represents a real challenge. In this paper, we propose a new resource management scheme which virtually reserves and releases resources at the network layer when necessary. Results show that our scheme distributes resources efficiently between Best Effort and Quality of Service traffics even when congestion arises.**

**Key Words:** ad hoc and sensor networks

## I. Introduction

Ad hoc network nodes operate in a very volatile envi- ronment where any connection could be dropped at any moment. A strategy is required to ensure predetermined service performance constraints. This strategy consists of avoiding the wastage of resources and interference with other on-going communications.

Resource management in ad hoc networks has two main functionalities which are, *admission control* and *resource reservation*. The source node investigates avail- able resources on the path towards the destination node before admitting the flow (*admission control*). If there are enough resources to carry the flow without inter- fering with any ongoing communication, corresponding resources are reserved (*resource reservation*) and trans- mission begins.

In this paper, we investigate the node's available band- width as a resource. Contrary to related works where the resource reservation is done at the Medium Access Con- trol (MAC) layer [1][2][3][4][5], our proposed scheme works at the network layer and is therefore independent of the lower layers. Moreover, most proposals do not take into account mobility in the resource management pro- cess which could result in degradation of performances [6]. Resource management performed at the network layer solves these issues since mobility information is provided by the routing protocol. The resource reser- vation scheme proposed here is virtual. Resources are controlled using routing information along with resource monitoring. Consequently, Quality of Service provided may vary but is ensured to remain within required guarantees at a maximum of 10% error. Furthermore, our proposed scheme provide fairness between different traffic classes in congestion cases. Robustness, simplicity and scalability of our proposed resource management model make it a good candidate for ad hoc networks as well as sensor networks.

The remainder of this paper is organised as follows: in Section II we discuss admission control within our scheme. In Section III we describe the proposed resource reservation technique. Next in Section IV, we present a performance analysis of our scheme incorporated in the AODV protocol. Finally, conclusions and proposed ideas for future works are presented in Section V.

## II. Admission Control

Admission control aims to provide a path, from source to destination, containing enough free resources to carry a flow, without interfering with nearby ongoing traffic. Since we are assuming a shared medium, the routing protocol must be able to access bandwidth related information of every node on the path, as well as their first hop neighbours.

### *A. Call Admission*

The call for transmitting is admitted only if the traf- fic rate, combined with corresponding interferences, is smaller than the minimum of the available bandwidth of each node belonging to the path, and their respective first hop neighbours. We call the traffic rate combined with corresponding interferences *predicted used bandwidth*. Figure 1 expresses the condition for call acceptance at each node supposed to be on the path.

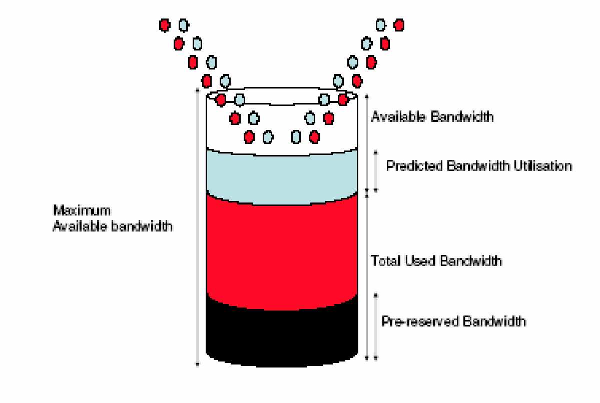


Fig. 1. Flow Accepted. *Predicted Bandwidth Utilisation Available Bandwidth* ⇒ *Call Accepted.*

If the Quality of Service guarantees provided can't be ensured anymore, due to link failure or degradation of the medium, one predetermined flow will be paused, as soon as the source receives the *QoS lost* information. Figure 2 shows the case where flow pausing is needed. In our proposed scheme, the information will be carried out by ICMP packets called *ICMP QOS LOST* packets. These messages along with the routing protocol control packets are used to do virtual resource reservation as described in section III.

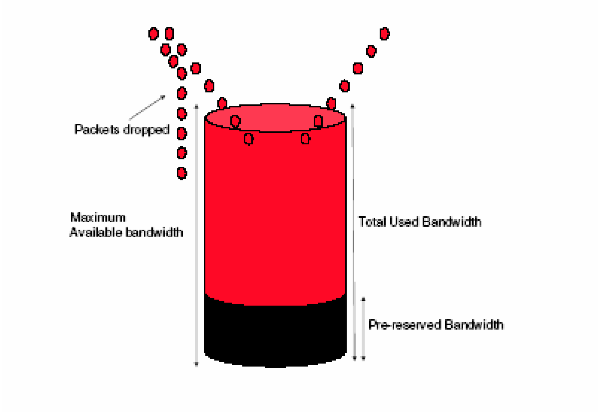


Fig. 2. One flow has to be paused since packets are dropped due to bandwidth overflow.

Classic network traffic is composed of different flows. One differentiate them as Quality of Service (QoS) enabled flows and Best-Effort (B-E) flows. The resource management model is supposed to ensure QoS guaran- tees for QoS flows at the expense of deteriorating B-E flows when necessary. Although QoS flows need greater priority than B-E flows, some fairness is necessary to avoid complete lost of all B-E packets in case of high QoS traffic load. In the resource management technique proposed, each node pre-reserves resources for B-E flows in case congestion arises. On Figure 1 and 2, the pre-reserved bandwidth is in black. This particular pre- reservation method is described more in detail in section III. Since B-E flows don't require any particular attention except in the case explained above, we assume that they do not need any admission control. Nevertheless, some QoS flows might be paused due to the pre-reservation for B-E packets associated to congestion:

- One pauses the heaviest flow to free more resources and maybe reaccept a lighter traffic. This strategy performs well when the network traffic is mainly composed of light flows. Unfortunately, the heaviest flow might be difficult to re-route since it needs more resources. This could result in a higher aver- age session pause time.
- One pauses the lightest flow to ensure a small paus- ing time and quick re-routing. Using this strategy, only few resources are freed. Hence, there is higher probability off

future congestion and, therefore flow pausing.

- Pausing the freshest flow could also be a good strategy. The most recent flow is easier to re-route since information concerning its route discovery might still be present in routing tables. On the other side, in case of general network congestion, recent flows might find it difficult to be carried without disturbance.
- If using source routing as routing strategy, selecting the flow having the nearest source might be the best solution. The source node would be informed more quickly when there is a lost of QoS guarantees.
- If the routing protocol is keeping updated informa- tion of energy consumption, as does most sensor network routing protocols, pausing the most energy consuming flow in case of congestion could save energy and extend the network lifetime.

One could also mix those techniques to obtain better results for predetermined scenarios.

## III. Virtual Resource Reservation

Our proposed scheme for resource reservation en- sures that there is enough available resources for the ongoing QoS traffic. In case of congestion, a part of the bandwidth is reserved for B-E packets in order to respect minimum fairness between QoS and B-E flows. Resources are not actually reserved. The MAC protocol distributes resources independently. That is the reason why we call our reservation proposal *virtual reservation*. At the network layer, the control of resources is done using bandwidth monitoring. At the MAC layer, we assume that traffic differentiation is implemented, QoS packets must be processed prior to B-E packets.

### A. Resource Estimation

We assume that the bandwidth is per node based (shared medium).

Each time we use the expression: *used bandwidth*, we refer to the maximum between the values of used bandwidth calculated at the actual node, and at it's first hop neighbours (equation (1)).

For the expression: *available bandwidth*, we refer to the minimum of the available bandwidth values of the same nodes enounced for the *used bandwidth* calculation (equation (2)).

$$BW_{used}(i) = \max_{\forall j \in [1stHOP(i)]} (BW_{used}(i), BW_{used}(j)) \tag{1}$$

$$BW_{avail}(i) = \min_{\forall j \in [1stHOP(i)]} (BW_{avail}(j), BW_{avail}(j)) \tag{2}$$

This estimation of both actual used and available bandwidths guarantee that nearby potentially interfering traffics are taken into account. Virtual resource reserva- tion accuracy is highly dependent on the estimation of available resources.

The available bandwidth used for call admission in subsection II-A can be calculated as follows:

$$BW_{avail} = BW_{max} - BW_{qos} \tag{3}$$

$BW_{qos}$ is the bandwidth used by the QoS packets, $BW_{max}$ the maximum bandwidth, and $BW_{avail}$ the available bandwidth.

Our estimation of the bandwidth used ($BW_{qos}$) is relatively simple. The calculation consists of adding up bits from QoS packets sent and received by a node over a predetermined period of time. Dividing the number of bits by this period of time gives us the used bandwidth. The actual maximum bandwidth ($BW_{max}$) is some- times complicated to calculate. For instance, MAC pro- tocol CSMA/CA, along with standard 802.11b, generates random waiting intervals before transmitting, when the channel is busy [7]. One says the limit is 11Mbps as defined by the standard, and one notices that packets are dropped due to bandwidth overflow when the actual used bandwidth is only 5Mbps. The actual maximum throughput is the maximum bandwidth ($BW_{max}$) we want to calculate. The maximum throughput can't be predicted with precision. Therefore, we update $BW_{max}$ with value of the total bandwidth used (B-E + QoS) whenever a packet is dropped due to bandwidth overflow (equation (4)). If $BW_{be}$ is the bandwidth used by B-E packets, we have the following:

$$BW_{avail} = 0 \Rightarrow BW_{max} = BW_{qos} + BW_{be} \quad (4)$$

Accurate bandwidth estimation, along with the use of control messages ICMP QOS LOST to free resources provide the resource management needed to fulfill Quality of Service requirements.

### *B. Congestion Case*

In the congestion case, we modified the network interface queue such that, when the queue is full, B-E packets are dropped prior to QoS packets. It ensures that QoS flows have absolute priority in the communication process. If the QoS traffic load becomes high, all B-E packets might be dropped. To avoid this scenario, our proposed scheme provide pre-reserved resources to be shared between B-E flows when congestion arises. The amount of pre-reserved resources to be attributed is part of the model specifications. It should be calculated depending on how congested the network might be, and on the balance between B-E and QoS traffics.

The traffic is differentiated at the bandwidth calcu- lation. $BW_{be}$ is the bandwidth used by B-E packets, $BW_{qos}$ the bandwidth used by the QoS packets, $BW_{res}$ the pre-reserved bandwidth and $BW_{pr}$ the predicted bandwidth utilisation for a specific QoS flow (see section II-A). When the bandwidth is not overflowed, QoS flows use all necessary available resources at the expense of stealing B-E traffic's resources. If the node's medium interface is congested, the routing protocol might react in three different ways depending on how resources are distributed. Figure 3 illustrates these three cases.

The following explains those possibilities more in details:

- *B-E flows are using more resources than allowed in congestion case ($BW_{be} > BW_{res}$).* This excess of resources attributed for B-E flows is considered as free resources for QoS traffic from the routing protocol point of view. A Call is accepted only if it doesn't imply stealing resources that are pre- reserved ($BW_{pr} < BW_{be} - BW_{res}$).

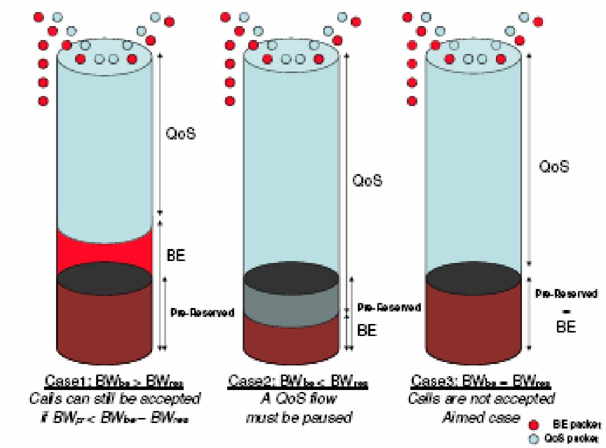


Fig. 3. Different Congestion Cases

- *QoS flows are using the pre-reserved resources ($BW_{be} < BW_{res}$).* Since we are in congestion case, pre-reserved resources must be freed for B-E flows. An ICMP QOS LOST is sent to the source node of a pre-chosen QoS flow which will, therefore, be paused while another route is found. Thus, pre-reserved resources become available for desperate B-E traffic.
- *B-E flows use the pre-reserved resources ($BW_{be} = BW_{res}$).* Resources are used as it should be, there- fore no action is taken by the routing protocol.

Since we modified the interface to prioritize QoS packets, theoretically no QoS packets should be dropped due to congestion unless QoS flows are using all avail- able resources (pre-reserved ones included). In that case, the source is informed as soon as possible, and packets are dropped only until one of the flows get paused.

## IV. Performance Analysis

### *A. Simulation Model*

We used Network Simulator (NS2) to perform the simulations. The results have been uniformed over 5 different mobility scenarios. We chose the Random Waypoint Model as the mobility model. Each node is going towards a random destination at a bounded random speed. The average node pause time has been set up to 100 seconds and the maximum speed to 5 meters per second. This nearly corresponds to casual walking pedestrians scenario. We decide to evaluate performances over traffic load. the Traffic pattern we use is composed of 10 B-E flows associated with 5, 10, 15 and 20 QoS flows respectively. Each traffic rate is approximately 200Kbps (Packet interval of 0.02 sec).

The model investigated in these simulations is rep- resentative of the virtual resource management scheme explained in the above sections except some functions enumerated below.

The calculation of $BW_{max}$ explain in subsection III- A hasn't been implemented on the model. We assume $BW_{max}$ to be constant and equal to 5.2Mbps. There is also no pre-reserved bandwidth for B-E traffic in this model. QoS flows have full priority.

Among the pausing strategies enumerated in subsec- tion II-B, we chose to pause heavy traffics with greater priority.
As a routing protocol, we extended our model with the Ad hoc On-demand Distance Vector (AODV) routing protocol [8] along with the QoS extensions proposed in [9]. Bandwidth information of each node's first hop neighbourhood is assumed to be known. We also use hello messages to keep neigbourhood information up to date.

As a Medium Access Control (MAC) Protocol, we used the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol along with 802.11b standard [7].

## *B. Results Interpretation*

We expressed the results using 5 different metrics that have been used in the literature before [10]. The bandwidth efficiency ratio (BWER) corresponds to the channel packet delivery ratio. It is representative of channel efficiency. The throughput relative error (TRE) is representative of error between QoS required and QoS provided, which corresponds, here, to traffic rate and throughput respectively. The session pause ratio equals the sessions pause time divided by the total session duration. We also use classic metrics known as the average end-to-end delay and the Packet Delivery Ratio (PDR). As explained in subsection IV-A we want to evaluate performances over increasing number of QoS flows: 5, 10, 15, and 20. Knowing that we have 10 B- E flows running, the ratio of QoS flows over BE flows varies as follows: 0.5, 1, 1.5, and 2.

Figure 4 illustrates the channel packet delivery ratio over QoS traffic load. Over an increasing number of QoS flows, the BWER for QoS traffic remains between 90% and 95% whereas B-E traffic BWER decreases linearly until below 90%. It proves the good operating of our scheme. QoS flows use resources efficiently even for high traffic load at the expense of deteriorating B-E flows.

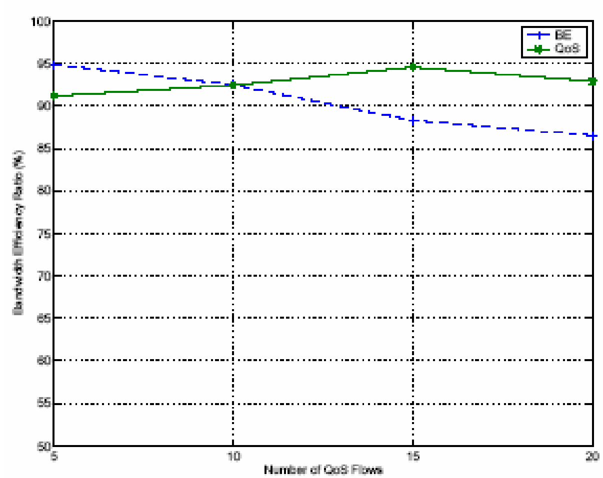


Fig. 4. Bandwidth Efficiency Ratio

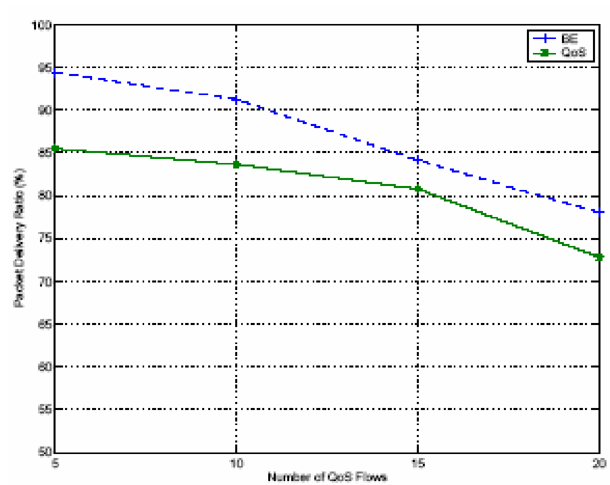


Fig. 5. Packet Delivery Ratio

Figure 5 shows the total packet delivery ratio for an in- creasing number of QoS flows. The QoS PDR decreases and remains below the B-E PDR for increasing traffic load. This is due to QoS session pausing. When a flow is paused, packets are dropped due to unreachable des- tination during re-routing process. B-E flows are never paused intentionally. Also, there is no call admission for B-E sessions which minimize the route discovery process delay. Although B-E packets seem to be transmitted with higher reliability, they aren't transmitted at the requested rate as shown by other results.

The throughput relative error is transparent to QoS provision. The aim is to have a throughput equal to the traffic rate which corresponds to a TRE of 0%. Figure 6 plots the TRE result for both kinds of flows over increasing QoS traffic load. As you can see on this figure, in the QoS flow case, the TRE never goes beyond 10%. Since the B-E flows are not supposed to use the resource management scheme, there is an uncontrollable increasing error, between throughput and requested rate, for B-E flows.

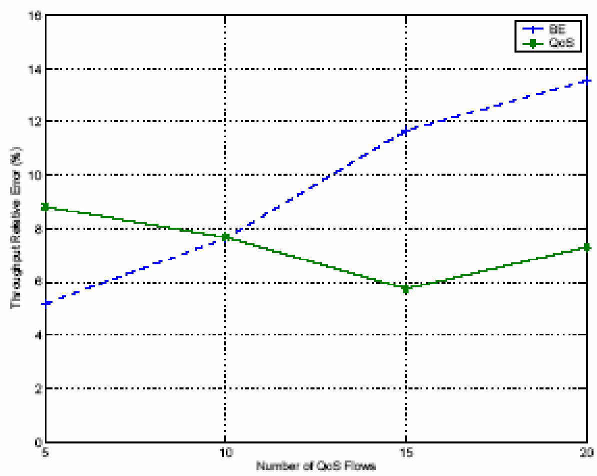


Fig. 6. Throughput Relative Error

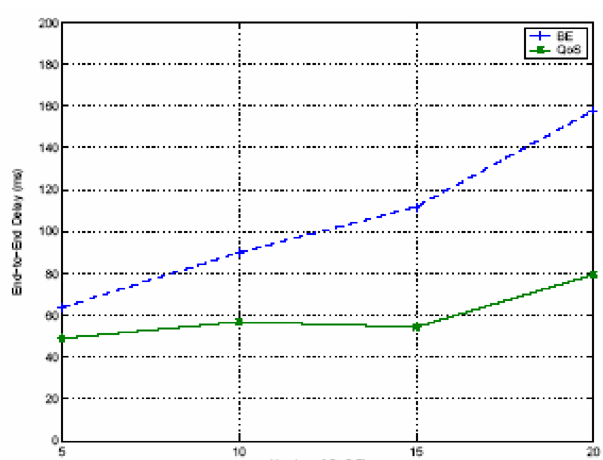


Fig. 7. End-to-End Delay

End-to-end delay along with bandwidth are the main QoS metrics used for QoS routing in ad hoc and sensor networks. These two metrics are highly coupled. If the bandwidth is used efficiently, the delay remains obviously low. This is what happens for QoS traffic on Figure 7. The QoS end-to-end delay remains below 80ms whereas B-E end-to-end delay increases proportionally with traffic load. It shows that QoS packets have priority over B-E packets as expected.

On Figure 8, the session pause ratio is plotted versus increasing QoS traffic load. In the B-E case, sessions are not paused, they are in deadlock state. It happens when sessions have to wait for the route discovery process to finish before transmitting the flow. The B-E session pause ratio increases with traffic load because routing packets find it harder to pass through heavy traffic. The session pause ratio for QoS sessions is much higher since the sessions are paused when there is a lost of QoS guarantees (see subsection II-A). Also, the route discovery process which does virtual resource reservation is more complicated and takes more time. If the B-E traffic load would have been increased instead of QoS traffic load, the session pause for QoS flows would have remained low.

## V. Conclusions and Further Work

A new resource management scheme has been devel- oped where admission control and *virtual* resource reser- vation is performed at the network layer. This scheme associated with a QoS extended protocols is able to handle Quality of Service in ad hoc and sensor networks. Results proved that resources are distributed correctly between B-E and QoS traffics when congestion arises. This research is at an early stage. More simulations needs to be done especially to investigate the effect of $BW_{max}$ estimation explained in subsection III-A, and the impact of pre-reservation explained in subsection III-B. Study the mobility impact on our proposed scheme is also part of the next step of this research.

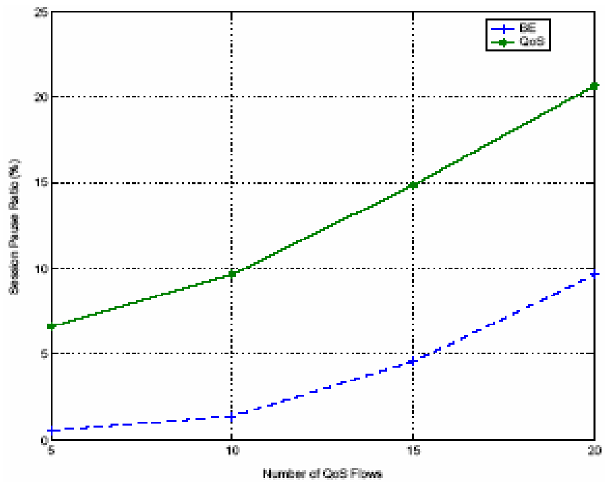

Fig. 8. Session Pause Ratio

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